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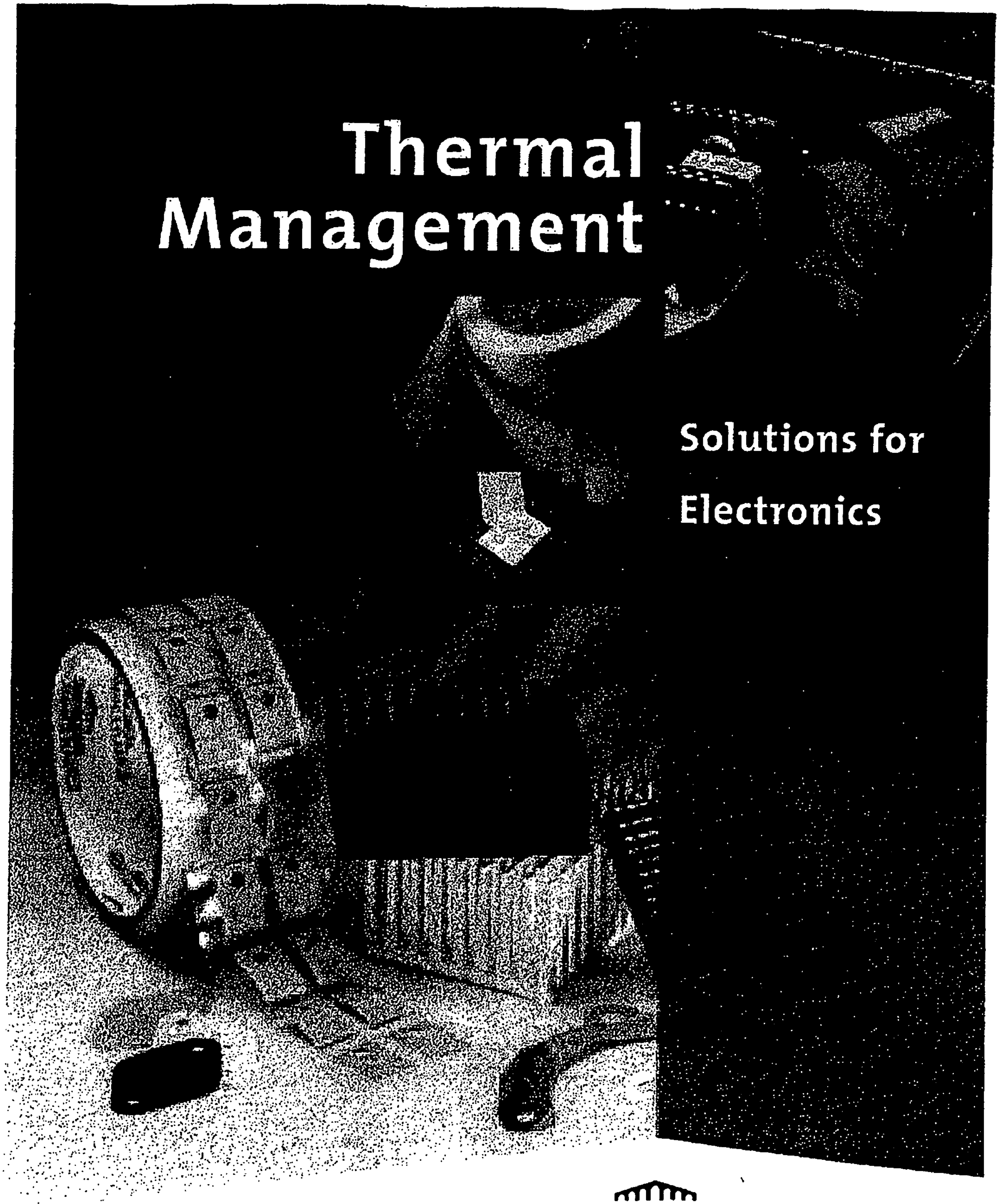
Thermal Management

Solutions for Electronics



SAINT-GOBAIN
PERFORMANCE PLASTICS

What is Thermal Management?

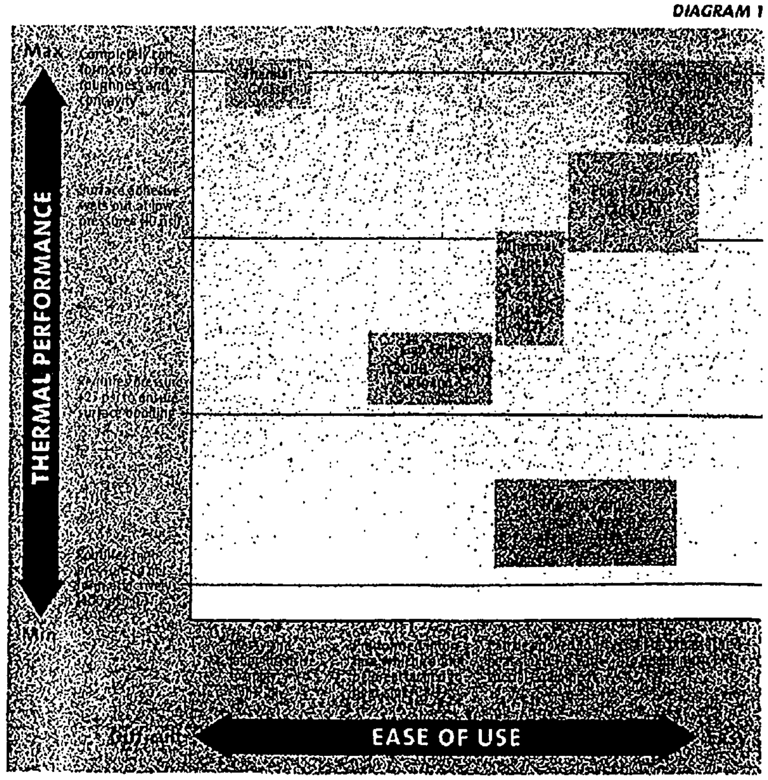
A thermal management system consists of materials designed to remove the heat generated by an electronic device (such as a power transistor or a microprocessor) to the ambient environment in order to ensure the reliable operation of the system.

Contents

ThermaCool Thermal Interface Materials Are Designed For Easy System Assembly

Saint-Gobain realizes that the competitive nature of today's computer assembly market requires automated mass production techniques. That's why our thermal management products are designed to provide an effective path for heat dissipation with minimal complication to the manufacturing process. In order to accomplish this objective, Saint-Gobain utilizes over 50 years of tape manufacturing experience to design thermal interfaces with creative materials and quality constructions that will deliver maximum performance. The result is a product line that balances the maximum thermal performance in a cost-effective form (see Diagram 1). Maximum thermal performance of a system is critical to optimize the processing speed and the expected life of modern microprocessors, and becomes even more crucial as the power of microprocessors and the power density of computer assemblies continue to increase. If a microprocessor is insufficiently cooled, it will operate at speeds lower than it is capable of. In addition, when a microprocessor is exposed to elevated temperatures for extended time periods, its operating life will be decreased or it can even be destroyed. Computer designers no longer need to sacrifice the thermal reliability of their systems in order to simplify the assembly process. Saint-Gobain allows designers to incorporate the necessary thermal interface while keeping their assembly costs to a minimum. This combination can produce a reliable system at a very competitive cost.

DIAGRAM 1



Background Theory of Thermal Management

The thermal performance of an electronic system is evaluated by combining the thermal performance (or effective heat transfer) at the three critical junctions of the system. These junctions cannot be eliminated from an electronic system. Thus, the thermal performance of a system is limited by the least effective of these junctions.

These three critical junctions that determine the thermal performance of a system are:

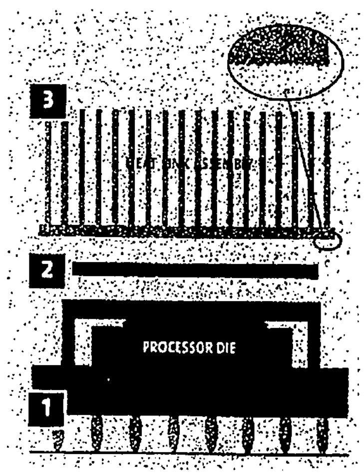
1. From the die to the lead frame and package within a microprocessor.
2. From the microprocessor to the heat sink.
3. From the heat sink to the ambient environment.

These junctions are illustrated graphically in Diagram 2 at right.

Junction 1 (below) is determined at the microprocessor manufacturer (prior to the involvement of a system design engineer) by the selection of:

1. Package type. (PGA, BGA, QFP, etc...)

DIAGRAM 2



2. Method of die attach.
3. Materials used in packaging and die attach.

Junction 3 (left) is controlled by the heat sink design and consideration of:

1. Air flow conditions.
2. Surface area of heat sink.
3. Shape and orientation of heat sink fins or pins.

The discussion that follows will focus only on Junction 2 which is the key interface between the top of the microprocessor heat spreader and the heat sink. By effectively designing this interface, it will provide optimum heat transfer between the microprocessor and the heat sink which allows the system to dissipate the maximum amount of heat.

Definitions for Thermal Interface Design

INTERFACE GAP

The gap which results between the microprocessor and the heat sink due to the stack-up of flatness specification tolerances. Two nominally flat surfaces will always produce an interface gap when placed together.

CONTACT RESISTANCE

In thermal transfer, air equals resistance. Thus, contact resistance is a theoretical measure of the volume of air voids along the interface of any two surfaces. These microscopic voids are formed by surface roughness, surface concavity or the interface material ineffectively conforming to a component's surface. This is illustrated in the magnified section of Diagram 2.

THERMAL CONDUCTIVITY

The ability of a material to conduct heat after the heat has entered that material. Thermal conductivity values can be misleading when used to evaluate thermal interface materials since actual performance is affected by the contact resistance with both the heat sink and the microprocessor. Thermal conductivity is typically expressed in units of W/m-K.

THERMAL IMPEDANCE

A defined parameter which is calculated by dividing the temperature difference across the interface by the power output of the microprocessor. Thermal impedance values are quite valuable in thermal management design since they inherently reflect the impact of contact resistances on interface performance. Low thermal resistances indicate a system which dissipates heat effectively. Thermal impedance is typically expressed in units of °C-in^2/W.

DIELECTRIC STRENGTH

A measure of the voltage required to cause a breakdown of a specific thickness of interface material. Dielectric strength is typically expressed in units of volts/mil.

CONTACT PRESSURE

The pressure between the microprocessor and the heat sink. This pressure is typically generated and maintained by the heat sink clips which attach to a socket. Contact pressure is typically measured in pounds per square inch (psi).

APPLICATION PRESSURE

The pressure required to attach an interface material to a heat sink or to a microprocessor. Application pressure is typically measured in pounds per square inch (psi).

Saint-Gobain's Thermal Test Methods

Saint-Gobain employs two standard thermal conductivity/thermal resistance test methods.

ASTM E1530

One is the guarded heat flow meter method, which conforms to ASTM E1530 (Diagram 3) and is mostly applicable to samples that range in thickness from 0.5 – 25mm. In this method an even reproducible pressure is applied to the test sample by pneumatic cylinders that allow test pressures ranging from 0 psi (contact) to 300 psi. The sample is held between two polished metal surfaces where the upper plate is heated and the lower plate is chilled, establishing a temperature gradient through the stack. The lower plate is also part of a calibrated heat flux transducer (HFT), as depicted in Diagram 3. Thermal conductivity can be determined by measuring the temperature resistance across the sample and using the output from the heat flux transducer according to the following general equations:

$R = [(T_U - T_M)/Q] - R_{int}$ where:

R — thermal resistance

T_U — upper plate surface temperature

T_M — lower plate surface temperature

Q — heat flux through the test sample

R_{int} — total interface resistance between sample and surface plates

$Q = N(T_M - T_L)$ where:

N — HFT (heat transfer coefficient)

T_M — lower plate surface temperature

T_L — bottom heater temperature

and subsequently,

$R = d/C$ where:

d — sample thickness

C — thermal conductivity

ASTM D5470

The other testing method is for thermal transmission properties of thin thermally conductive electrically insulating materials, which conforms to ASTM D5470 and is applicable to samples ranging in thickness from 0.02 – 10mm. In this method an even reproducible pressure is applied to the test sample by pneumatic cylinders that allow test pressures ranging from 0 psi (contact) to 500 psi. The sample is held between two polished metal surfaces where the lower plate is heated and the upper plate is chilled, establishing a temperature gradient through the stack that is measured via 4 thermocouples, as depicted on Diagram 4. Thermal impedance can be determined by measuring the temperature resistance across the sample according to the following general equations:

$Q = V \times I$ where:

Q — heat flow, W

V — electrical potential applied to the heater, V

I — electrical current flow in the heater, A

Temperature of the upper meter block is defined as:

$T_A = T_2 - (d_B/d_A)(T_1 - T_2)$ where:

T_A — temperature of the upper meter block surface in contact with the specimen, K

T_1 — upper temperature of the upper meter block, K

T_2 — lower temperature of the upper meter block, K

d_A — distance between temperature sensors, m

d_B — distance from the lower sensor to the lower surface of the upper meter block, m

Temperature of the lower meter block is defined as:

$T_D = T_3 - (d_D/d_C)(T_3 - T_4)$ where:

T_D — temperature of the lower meter block surface in contact with the specimen, K

T_3 — upper temperature of the lower meter block, K

T_4 — lower temperature of the lower meter block, K

d_C — distance between temperature sensors, m

d_D — distance from the upper sensor to the upper surface of the lower meter block, m

Thermal impedance can be calculated:

$\Theta = (T_A - T_D) \times A/Q$

To obtain thermal conductivity a plot of thermal impedance (y-axis) versus various sample thicknesses is generated. The slope of the straight line is the reciprocal of thermal conductivity. The y-intercept is the interfacial thermal resistance, which is dependent on clamping force and surface.

DIAGRAM 3

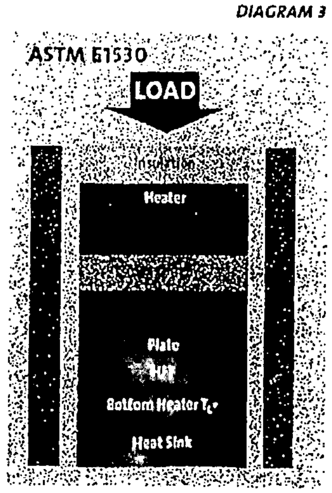
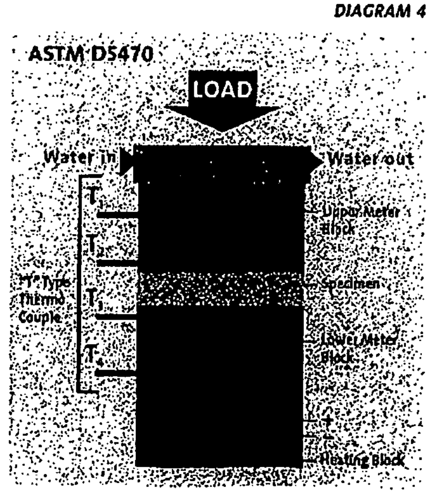


DIAGRAM 4



How Thermal Interface Materials Ensure More Dependable And Reliable System Operation

The most influential factors affecting thermal interface performance are reviewed in detail below.

INTERFACE GAP

The key to maximizing the thermal interface performance of a system is eliminating as much ambient air as possible from the interface gap. Filling the gap with a highly conformable, thermally conductive material is one of the most effective means of accomplishing this. Using a highly conformable material can minimize the negative effect of contact resistance generated by microscopic peaks and valleys along the heat sink surface while compensating for surface concavity. Determining the height of the interface gap is critical, since maximum thermal efficiency requires that interface material completely fill the gap to eliminate any air voids. However, when the interface material is thicker than necessary, the heat is forced to flow through this excess material to reach the heat sink. This contributes unnecessary additional thermal resistance to the system. The effect of interface gap on the interface thermal resistance is illustrated in Diagram 5. This diagram illustrates that the thermal resistance increases linearly with interface thickness. In addition, it indicates two important aspects of thermal interface performance of a system:

1. The plot's slope is inversely proportional to the thermal conductivity of the interface material.
2. The plot's y-intercept is proportional to the contact resistance of the system.

ELECTRICAL REQUIREMENTS

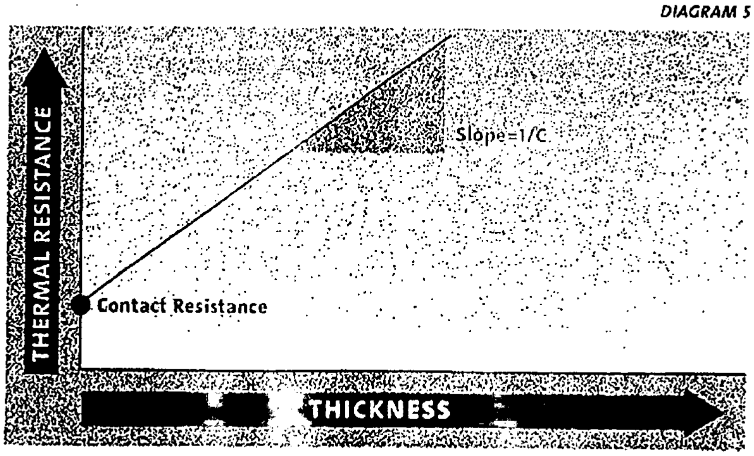
Traditional thermal interface materials have always provided electrical isolation at the expense of thermal resistance. Electrical isolation requires the use of dielectric materials within the construction, and exacts a tremendous cost on the thermal performance of the interface material. The performance of the interface material can be greatly improved by eliminating the dielectric materials and including only conductive materials in the formulation. Since microprocessors provide electrical isolation of the die within the package, computer system designers are often able to choose from a variety of lower thermal resistance interface materials.

Computer system designers may consider thermal interface materials that provide dielectric strength for densely populated circuit boards. As circuit designs become increasingly dense, system designers may utilize electrically isolating thermal interface materials to ensure that a misplaced interface does not short out the system. When evaluating electrically isolating materials, the dielectric strength should also be considered. The material must withstand the worst case voltage spikes possible in the system to guarantee system dependability.

CONTACT PRESSURE

The contact pressure on the interface material is generated by the heat sink attachment method. The typical attachment method for microprocessor heat sinks is spring clips, which produce approximately 5 to 15 pounds of pressure. High contact pressures would improve the thermal performance of interface materials since pressure will force air from the interface surface as well as force conformance of the interface material itself. In other words, high contact pressures can minimize the contact

DIAGRAM 5



How Thermal Interface Materials Ensure More Dependable And Reliable System Operation

resistance of a system. Unfortunately, many microprocessors are not durable enough to withstand high contact pressures. The thermal cost of applying a low contact pressure to a system will be dramatic if a highly conformable interface material is not selected. Thermal resistance values will rise under low contact pressure, since these values inherently reflect the contact resistance of the system. The graph in Diagram 6 reflects the measured magnitude of this impact on several actual interface materials. Generally speaking, thermal resistance will typically be three times higher at low contact pressures than at high contact pressures (ie., 300 psi).

THERMAL RESISTANCE

Thermal resistance measurements are the most effective means of evaluating interface materials, since these measurements inherently reflect the impact of contact resistance on the system's thermal performance.

Thermal resistance is minimized when the interface between two surfaces meets the following conditions:

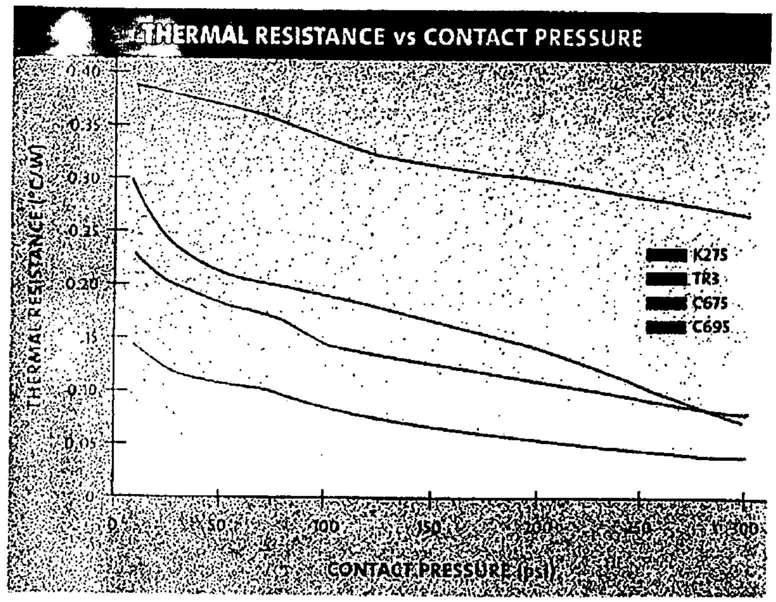
1. Interface contains high thermally conductive fillers.
2. Interface completely conforms to all surface roughness on both surfaces.
3. Interface completely and exactly fills the gap between the two surfaces.

Thermal resistances measured under standard test methods (as described in the "Test Methods" section of this brochure) should take care to meet the following controlled "ideal" conditions:

1. Flat interface surfaces.
2. Uniform contact pressure.
3. Uniform heat flow over the test area.
4. All heat loss occurs through interface material.

In order to accurately reflect the thermal resistance of an interface material in a given system, the test setup must carefully simulate the system operation. This must include a test setup that reflects the surface roughness, the surface concavity, the application pressure and the microprocessor power of the actual system. It is critical that thermal resistance values of different interface materials are measured at the same contact pressures. In fact, it is impossible to accurately compare interface materials that are evaluated under different test conditions. Furthermore, these thermal resistances should be evaluated over the entire contact surface area rather than normalizing the thermal resistance to a one-square-inch area. Normalizing a thermal resistance value can give misleading results, since this calculation improperly assumes uniform heat flow over the test area.

DIAGRAM 6



Saint-Gobain Has The Right Thermal Interface Material For Your Application

RECOMMENDED STEPS IN CHOOSING A THERMAL INTERFACE

1. Determine Electrical Requirements

Electrical Isolation	Dielectric Strength	Typical Values	Typical Product Choices
Required	High	> 1500 V/mil	Kapton Tape
Required	Low	< 300 V/mil	Silicone Coated Fabric Gap Fillers
Not Required	N/A	N/A	Transfer Adhesive Aluminum Tape Graphite Tape

2. Determine the Interface Gap

Interface Gap Values	Typical Product Choices
< 2 mil	Transfer Adhesive
2 – 5 mil	Aluminum Tape Kapton Tape
5 – 18 mil	Silicone Coated Fabric
> 18 mil	Gap Fillers

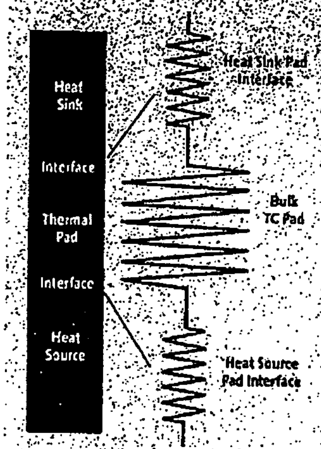
3. Determine the Contact Pressure

Contact Pressure	Typical Values	Typical Product Choices
Very low	< 10 psi	Gap Fillers
Low	< 20 psi	Transfer Adhesive Aluminum Tape Kapton Tape Graphite Tape
High	300 psi	Silicone Coated Fabrics

4. Choose the Lowest Thermal Conductivity or Impedance

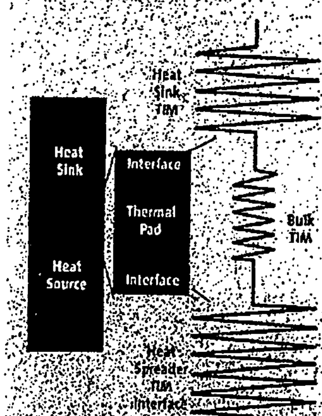
- The above steps will have narrowed the potential list of interface choices.
- Thermal resistance values should be measured under conditions as close as possible to the actual application.
- Test conditions must be the same in order to compare thermal resistance values.
- Depending on the application given performance can be governed by bulk thermal conductivity or thermal impedance, as depicted in diagrams at right. It can also be depicted in terms of "resistor in series" model.

GAP FILLERS



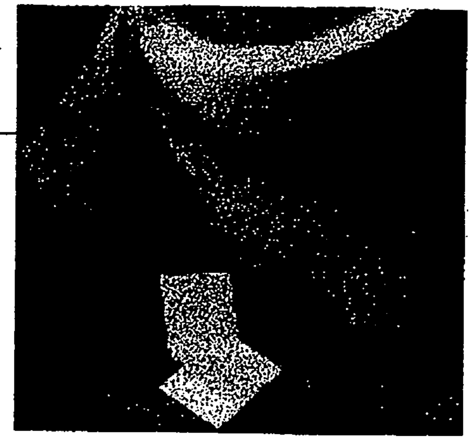
Gap fillers, coated fabrics and some tapes — largest resistance is due to thickness

PHASE CHANGE



Phase change and transfer adhesives — largest resistance is due to interfaces

Thermal Phase Change



PRODUCT OVERVIEW

The ThermaCool family of phase change materials provides solutions to challenging thermal management problems. These products can be used in place of messy thermal greases, provide excellent thermal coupling between components and heat sinks, and can alleviate all the problems associated with thermal greases such as migration, pump-out, and uneven bondline. The thermal impedance of ThermaCool phase change products is comparable with that of thermal grease. The phase change materials are designed to provide either bondline adhesion or lack of it for better rework ability.

Product Name	CONSTRUCTION				THERMAL		
	Color	[illegible]	Reinforcing Carrier	Thickness (mils)	Phase Change Temperature (°C)	Thermal Conductivity (W/mK) ASTM E1530	Thermal Impedance (°C in.²/W) ASTM E1530
C1055	Orange	BN	None	3.0	45	1.0	0.04
C1060†	Orange	BN	Fiber glass	3.5	45	0.7*	0.10
C1095 x 01†	Pink	ZnO	Thermal Film	3.0	>50	0.6	0.13
C1100	White	BN	None	3.0	35	1.0	0.03
C1100F	White/ Silver	BN	Aluminum foil	4.0	35	1.0	0.05

† Product engineered to prevent sticking to the internal heat spreader for improved shock and vibration performance
**Compound only*

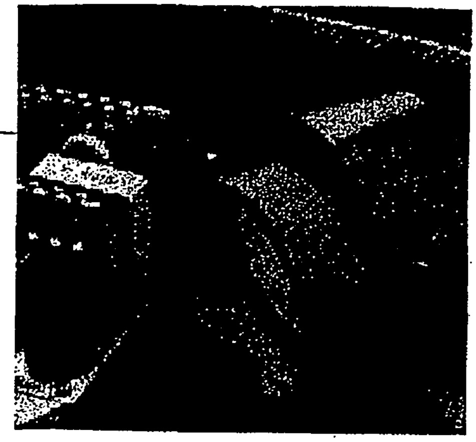
Application Advantages

- Lowest thermal impedance thermal interface materials.
- Minimizes system assembly cost by allowing for pre-attachment to the heat sink or CPU.
- Softens and conforms to surface roughness or concavity at operating temperature.
- Operates at low clip pressures (5 to 10 psi).
- Applies and repositions with thumb pressure for easy field service.
- Allows for vertical mounting due to cohesive properties.

Key Product Properties

- Unique, patented formulations give lowest thermal impedance in the ThermaCool product family.
- Supplied as die cut tabs on a roll to provide a manufacturing friendly replacement to thermal grease.
- Matrix is optimized to provide superior surface interaction for best thermal coupling between microprocessor case and heat sink.
- Provides simplified component assembly and allows rapid re-work.

Thermal Tapes and Transfer Adhesives



PRODUCT OVERVIEW

The ThermaCool family of high performance thermally conductive Pressure Sensitive Adhesive tapes provides solutions to difficult thermal management problems. These products can be used in place of mechanical fasteners, provide excellent thermal coupling between components and heat sinks, and can accommodate materials of different coefficients of thermal expansion with the compliant interface. All of the adhesives are flame retardant and are formulated for high performance adhesion while still being easily re-workable without damage to sensitive components.

Product Name	CONSTRUCTION			MECHANICAL	ELECTRICAL	THERMAL	
	[illegible]	Color	Thickness (mils)	Adhesion (oz./in.²)	Dielectric Strength (volts total)	Thermal Conductivity (W/mK) ASTM E1530	Thermal Impedance (°C in.²/W) ASTM E1530
K271 K275	Kapton Based	Green/ White	4.5 5.0	30.0 (60.0)[1] 30.0 (60.0)[1]	7000 6500	0.6 0.4	0.4 0.1
C675	Aluminum Based	Silver	6.0	30.0 (60.0)[1]	Non-insulating	2.0	0.1
C695	Graphite Tape	Black	6.0	5.7 (1 min.)[2] 6.7 (20 min.)[2]	Non-insulating	2.0	0.12
C6910	Graphite Tape	Black	11.0	5.7 (1 min.)[2] 6.[illegible] (20 min.)[2]	Non-insulating	2.6	0.16
TR3 TR5	Transfer Adhesive	White	3.0 5.0	3[illegible] 30	N/A	0.4 0.4	0.3 0.5

1 Adhesion to steel (value [illegible] thermosetting); 2 Adhesion to aluminum

Application Advantages

Graphite Tapes

- Spreads heat evenly to allow for maximum heat sink potential at low pressures.
- One-sided adhesive construction allows for easy re[illegible] r[illegible]ement or upgrade of compo[illegible]s.
- Pressure-sensitive a[illegible]esive tape can be preapplied to a hea[illegible]k t[illegible] minimize assembly costs.
- Flame-retardant version available.
- Available in slit-roll[illegible] die-cut shapes.

Transfer Adhesives

- High peel strength a[illegible]hesion to minimize air entra[illegible]t.
- Material can be pr[illegible]d to a heat sink or other t[illegible] conductive material.
- Adverse effects of surface roughness are minimized thro[illegible] a highly con-formable pressure-[illegible]itive adhesive.
- Flame-retardant version available.
- Available in slit-rolls or die-cut shapes.

Thermal Aluminum Tape

- Designed to exhibit excellent thermal pr[illegible]ties [illegible] 10 psi.
- High peel [illegible]ength adhesion to mini-mize air e[illegible]pment.
- Material can be pre-attached to a heat sink or CPU.
- Adverse effects of surface roughness are minimized through a highly con-formable pressure-sensitive adhesive.
- Flame-r[illegible]tardant version available.
- Avail[illegible] in slit-rolls or die-cut shapes.

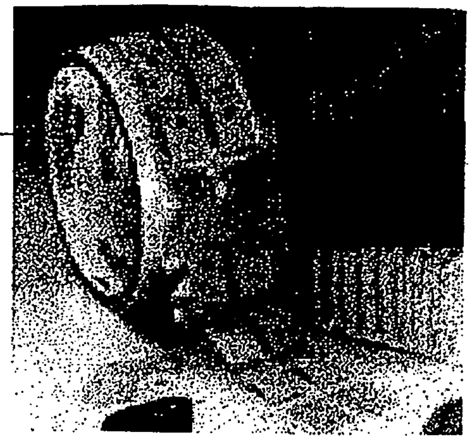
Thermal Kapton® Tape

- Kapton ([illegible]) provides excellent dielectric [illegible]ength with minimal thermal r[illegible]stance.
- High peel [illegible]ength adhesion to mini[illegible] entrapment.
- Mater[illegible] can be pre-attached to a heat sink [illegible]U.
- Adverse effects of surface roughness are minimized through a highly con-formable pressure-sensitive adhesive.
- Flame-retardant version available.
- Available in slit-rolls or die-cut shapes.

Key Product Properties

- Thermally conductive ceramic filled acrylic adhesive system with integral flame-retardant package used on all products.
- Silicone adhesive system is available for special applications.
- Low thermal impedance and good ther-mal conductivity provide superior heat transfer performance.
- Allows thermal expansion differences between electrical components and dissipation devices to be easily accommodated while maintaining high thermal transfer rates.
- Provides ease of component assembly and allows rapid re-work.
- Can be easily die cut for simple, low cost application.

Thermal Fabrics



PRODUCT OVERVIEW

The ThermaCool family of high performance thermally conductive coated fabrics provides solutions to difficult thermal management problems. These products can be used for low cost thermal transfer requiring minimal thickness and high physical and mechanical characteristics. The fiberglass/silicone compound construction provides excellent cut-through resistance, thermal transfer pad and electrical isolation. Thickness ranges from .007 to .018 inch to fill the need of the varying gap requirements.

	CO[illegible]ON			MECHANICAL			ELECTRICAL		THERMAL	
Product Name	Color	[illegible]	[illegible]ller	UL Listing Recognit[illegible]	Brea[illegible] Str[illegible]	Elongation (psi)	Volume Resistivity (ohm-cm)	Dielectric Strength (volts [illegible])	Thermal Conductivity (W/mK) ASTM E1530	Thermal Impedance (°C in.²/W) ASTM E1530
TF407	Gray	7	Alumina	V-0	[illegible]	<5	1×10^{14}	3500	0.9	0.31
TF409	Gray	9	Alumina	V-0	[illegible]	<5	1×10^{14}	4000	0.9	0.39
TF509	Blue	9	Alumina/BN	V-0	100	<5	1×10^{14}	2500	2.0	0.18
TF1818	Gray	18	Alumina/BN	V-0	60	<5	1×10^{14}	9000	1.0	0.71
TF1877	Green	[illegible]	[illegible]mina/BN	V-0	[illegible]	<5	1×10^{14}	3000	1.2	0.23
TF1879	Green	[illegible]	[illegible]/BN	V-0	[illegible]	<5	1×10^{14}	3500	1.2	0.29

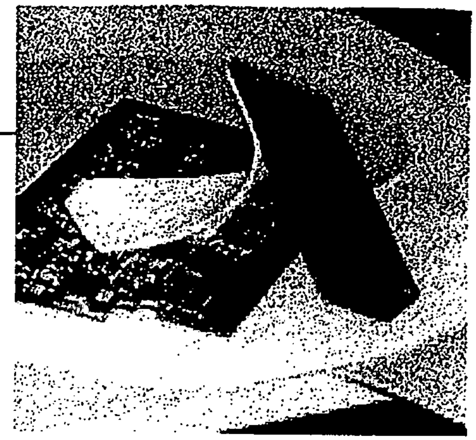
Application Advanta[illegible]

- Products to fill the need [illegible]ing component clamping f[illegible] methods.
- Electrically isolating com[illegible]s while providing exc[illegible]al transfer to heat sinks.
- Electronic modules for [illegible]pplies and telecommunicatio[illegible]
- Fits between CPU and [illegible]ler.
- Heat transfer pads in m[illegible] modules.
- CD ROM cooling.
- Heat pipe assemblies.

Key Product Properties

- Glass fa[illegible]ric reinforcement provides excell[illegible] ele[illegible]rical isolation as well as good [illegible]ugh resistance.
- Variety [illegible] finishes and thickne[illegible]ailable to optimize therm[illegible]ance.
- High p[illegible]ce thermally condu[illegible]e c[illegible]nic particles provide excellent thermal performance.
- Designed to allow easy die cutting for [illegible] cost application.
- Some [illegible] can be supplied with a[illegible]dhesive.

Gap Fillers



PRODUCT OVERVIEW

The ThermaCool family of high performance thermally conductive gap fillers provides solutions to difficult thermal management problems. These products can be used to fill gaps and enhance thermal performance of the electrical system. ThermaCool gap fillers can accommodate materials of different coefficients of thermal expansion with the compliant interface. The ThermaCool gap f[illegible] family includes products in a variety of thicknesses and a range of hardness valu[illegible] to effectively close gaps while providing the therma[illegible] transfer needed in demanding electronic applications.

Product Name	CONSTRUCTION			MECHANICAL		ELECTRICAL	THERMAL	
	[illegible]	[illegible]	Reinforce[illegible]	UL Listing Recognition UL 94	Hardness (Shore A)	Dielectric Strength (vol[illegible])	Thermal Conductivity (W/mK) ASTM E1530	Thermal Impedance (°C in.²/W) ASTM E1530
TC3001*	Red	15–220	None	V-0**	5–10	300	1.6	1.2
TC3001HCT	R[illegible]	15–220	None	V-0**	5–10	300	3.0	1.2
TC3002*	Red	15–220	None	V-0**	25–30	300	1.6	1.2
TC3005*	Red	15–220	N[illegible]	V-0**	<5	300	1.6	1.2
TC100	[illegible]	[illegible]	N[illegible]	HB	65	250	1.3	1.25
TC100U	[illegible]	[illegible]	N[illegible]	—	65	[illegible]	1.3	1.25
R10404	Lt. G[illegible]	1/32"–1/[illegible]"	None	V-1	13	100	0.3–0.65	6.0–1.1

Products can be supplied w[illegible] [illegible]glass or aluminum foil—please call for availability
***V-0 > 20 mils, V-1 20 mils [illegible]*

Application Advantages

- Filling areas of [illegible] faces to provide a therm[illegible] [illegible] to [illegible] heat sink.
- Electrically isolatin[illegible] [illegible]ponents while providing g[illegible] [illegible]mal transfer to heat sinks.
- Fits between CPU a[illegible] [illegible] t spreader.
- Heat transfer pads i[illegible] [illegible]ry modules.
- CD ROM cooling.
- Heat pipe assem[illegible]

Key Product Properties

- [illegible]rietary silicone polymer matrix is f[illegible]ulated to give a range of hardness a[illegible] provide integral tack to minimize th[illegible]mal impedance.
- Ha[illegible]en-free additive package provides UL [illegible] performance.
- D[illegible] to allow easy die cutting for s[illegible] cost application.
- S[illegible] [illegible]sive systems are available f[illegible]ome [illegible]ri[illegible]ls and others have s[illegible]cient [illegible]ck [illegible] provide self-adhesion.

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TO:	Examiner Alicia Chevalier	**YOUR REF:** *Serial Nos.:*	10/361,972; 10/364,491; and 10/364,579
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